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Small hydropower plants in Serbia: Hydropower potential, current state and perspectives

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ABSTRACT

The utilization of renewable resources for energy production is a very topical issue in Serbia, both among experts and among the public. Having in mind that hydropower potential is considered the most important renewable resource (31,000 GWh per year) which is only partially exploited (10,000 GWh per year), accent is laid on the possibilities for its complete utilization through construction of small hydropower plants (SHPs). Accordingly, the paper presents the historical development of SHPs in Serbia, the current situation, an overview of the institutional, legal and planning framework regulating the selection of suitable locations, permit issuing procedures and functioning of SHPs. The study includes an overview of 31 active SHPs in Serbia and 21 locations at which construction of new facilities has been planned and approved by the responsible ministry. Special attention has been paid to the prospects for the development of SHPs through an analysis of hydropower potential and possible locations for the construction of new facilities in various regions and municipalities in Serbia, as well as to the complementary utilization of water management facilities for energy production. In conclusion, the paper points out practical problems that hinder and impede further development of the network of SHPs and suggests possible ways to overcome them.

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Contents

1. Introduction

In most countries, the late 20th and the early 21st century could be described as decades during which technical, technological, economical and social development have reached an exceptionally high level due to the energy resources and their exploitations. As the

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awareness of the need to protect environmental quality and ensure a rational utilization of resources has become globally present in the same period, gaining legitimate forms of support, the concept of a sustainable economic development in the future is based on the introduction and utilization of renewable energy sources. While the developed countries of the European Union have set the goal to ensure a 20% share of energy from renewable sources until 2020, a great number of developing countries, including Serbia, are still striving to identify such sources and provide the fundamental preconditions for their more intensive utilization in the future. The availability and potential of particular renewable energy sources are geographically determined and they are reflected on the economic cost-effectiveness of their utilization.

Among renewable energy sources, hydropower and the potential for its exploitation by constructing hydropower plants have a very important place. In rural areas and particularly in mountainous regions, which are usually economically passive and not easily accessible, small power plants up to 10 MW appear as a cost-effective energy production technology [1].

In various countries, various definitions and classifications of small power plants are used; they inevitably reflect the role and significance assigned to these facilities upon construction. Commonly, various parameters (development of electrical power industry and the overall economic development of a country, available water resources, the availability of energy raw materials, natural topographic features, etc.) are involved in determining the upper limit of the installed power; accordingly, different upper limit values are mentioned in literature.

The guidance and information documents published in the European Union do not propose a uniform approach to classifying small hydropower plants (SHPs). The maximum allowed installed capacity for SHPs varies from 3 MW in Luxemburg, 5 MW in Germany, to 12 MW in France. The measures aimed at supporting SHPs in Austria depend not on their capacity, but on the amount of electrical energy produced in them. Outside Europe, in countries like Brazil, US, Russia, the capacity of SHPs is limited to 30 MW, while in China the upper limit for SHPs is 50 MW. However, in recent years, the following classification of SHPs based on their combined power capacity and the capacity of a single unit is becoming widely adopted:

- up to 0.01 MW—pico HPs;
- up to 0.1 MW—micro HPs;
- up to 1 MW—mini HPs; and
- up to the combined power capacity reaching 30 MW and the capacity of a single power unit reaching 5 MW—small HPs.

In the last case, the maximum capacity of a single unit is sometimes limited to 10 MW rather than 5 MW [2].

The installed capacities of SHPs in the EU and the world have increased from 5900 MW (EU) and 19,000 MW (world) in 1980 to 10,300 MW (EU) and 46,000 MW (world) in 2005 [3]. The amount of electrical energy produced in SHPs in EU was expected to reach 55 TWh in 2010, whereas their combined capacity was expected to be 14 GW. More than 90% of the installed small hydropower facilities are concentrated in six member states of the EU-27: Germany, Spain, France, Italy, Austria and Sweden. According to data provided by the European Small Hydropower Association (ESHA), Austria has the greatest share of SHPs in the total installed capacity – 4.89% and in total electricity production – 6.87%, whereas Germany has the greatest share of SHPs in the total capacity of hydropower stations – 16.67%. Among the countries that have recently joined the European Union, the greatest number of SHPs have been constructed in the Czech Republic (more than 1000), Poland, and Slovenia [2]. China is the leader in the development of small hydropower facilities. In 2004, China's total installed capacity of SHPs was 34.66 GW, whereas its generating capacity was 97.79 TWh, which is the highest in the world [4]. Intense development of SHPs is observed in Turkey [5,3,6–8], India [9], Brazil [10] and expected in many African countries, like Angola, Ethiopia, Tanzania and Nigeria [11].

2. Hydropower potential

Taking into consideration geomorphological and hydrological characteristics of the terrain, Serbia's hydropower potential has been estimated at 31,000 GWh per year, 17,000 GWh of which are technically usable. The existing large hydropower plants use about 10,000 GWh. The remaining 7000 GWh could be used by constructing large (75%) and small (25%) hydropower plants. The potential of small watercourses suitable for installing mini hydropower plants reaches 0.4 million tonnes of oil equivalent or 3% of the total potential of renewable sources in Serbia [12].

Most mountains in Serbia are relatively rich in water, with rivers running steeply downwards in short sections of the stream, which ensures favorable conditions for their exploitation for energy production. Although all preconditions in terms of the position of rivers, topographic and hydrological conditions are met, the attention paid to this problem is still insufficient and there is a lack of action in dealing with it.

Until recently, the utilization of hydropower in flatland areas like Vojvodina (northern part of Serbia) was a neglected issue though these regions have a considerable hydropower potential. However, earlier analyses have shown that its exploitation would not be economically justified. The key feature of this area is that it is traversed by large watercourses with a low possibility of the concentration of downward flow, which is the most important precondition for the utilization of hydropower potential. Due to large amounts of water, it would be necessary to build high-capacity facilities and to raise artificially the water level in order to ensure the concentration of downward water flow. These two factors would have the crucial role in the high cost of the energy produced this way. The Danube–Tisza–Danube hydrosystem has a particular importance for the utilization of hydropower potential, first of all, for micro hydropower plants. It serves a multitude of purposes: drains the excess water during humid season, provides necessary water for irrigation in dry seasons, supplies water to industry and some settlements around the main canal network, and it is used for navigation, fishing, etc. With its construction, Serbia got 664 km-long high-quality navigable network [13]. In order to ensure water regime management, a great number of new facilities, like water-gates and pumping stations, have been constructed; it is also possible to build mini hydropower plants near the existing facilities, where water steps have already been formed. In order to make the construction of hydropower plants cost-effective, it is necessary to regulate the water regime within a hydrosystem so as to ensure increased energy production without reducing its basic functions, which still have priority.

Considering that hydropower potential is strongly correlated to the changes in water discharge, it is necessary to estimate the impact that global climate change could have on it. Such an analysis was performed in the study by Lehner et al. [14]; they presented a model-based approach to the analysis of possible effects of global climate change on Europe's hydropower potential at a country scale. The authors made an overview of today's hydroelectricity generation potential and its mid- and long-term prospects by comparing current conditions of climate and water use with future scenarios. For the entire Europe, the gross hydropower potential is expected to decline by about 6% by the 2070s, while the developed hydropower potential will show a decrease of 7–12% [14]. According to the results of this study, following

moderate climate and global change scenario assumptions, severe alterations in discharge regimes may be expected in future, leading to unstable regional trends in hydropower potential with a reduction of 25% and even more in the countries of southern and southeastern Europe, including Serbia.

3. Small hydropower plants in Serbia

3.1. Historical development of small hydropower plants in Serbia

Small hydropower plants have a long tradition in Serbia. A significant number of SHPs have been built there and some of them are still in use. Other facilities were closed and dilapidated and many of them are in a ruinous condition. The hydropower plant Pod Gradom on the Đetinja River was the first such facility in Serbia. This plant, installed in 1900, was based on Nikola Tesla's principle of three-phase alternating current. Between 1900 and 1940, 26 SHPs were built; 10 of them are still in use [15]. After World War II, the national electricity production policy was briefly focused on the study and construction of SHPs. Due to a very low cost of electricity, light distillate oil and mazut for thermal power plants, during that period, such facilities were only exceptionally built and their construction was considered economically unjustified [16]. However, several dozen hydropower plants of this type had been installed before the focus was switched on the construction of electricity plants on large rivers (Đerdap, Bajina Bašta, etc.). Further studies of the hydropower potential of small watercourses were abandoned—unjustifiably, having in mind their potential. In the past, Vojvodina's hydropower potential was used as a moving power for water-mills and electricity production in small hydropower facilities for local needs. Mills that occasionally use hydropower (water-mills on the Karaš River: Jasenovo, Straža, Vojvodinci) can still be found, whereas hydropower facilities are not used any more and they have merely a museum interest [17].

In the late 1980s, the *Survey of Small Hydropower Plants in the Republic of Serbia* (1987) [18] and the *Survey of Small Hydropower Plants in Vojvodina* (1989) were drafted. These documents include a detailed study of the energy potential of watercourses and selected locations for the construction of SHPs. According to the mentioned surveys, 856 locations suitable for the construction of such facilities were identified in Central Serbia and additional 13 in AP Vojvodina. Due to turbulent economic and political changes that followed in the 1990s, the ideas underlying these studies were not put into practice. However, their results are still used when choosing potential locations for the construction of SHPs. According to the results of 15 recently completed preliminary feasibility studies on the construction of small hydropower facilities, under the present economic conditions, it would be possible to install them on 5–10% of the total locations foreseen by the *Survey*. These studies also include elements of a draft project.

3.2. Current state of small hydropower plants in Serbia

According to Serbian regulations, until December 2012, the term “mini hydropower plants” covered all hydropower plants with the installed power up to 10 MW regardless of their type (i.e. it included both plants using reservoirs and run-of-river hydropower plants). However, since the adoption of the Decree on Incentive Measures for Privileged Electric Power Producers [19] in January 2013, this term has been extended to include hydropower plants with the installed power up to 30 MW. The hydropower plants with the installed power up to 100 kW are called microenergy plants [20]. Apart from power, SHPs may also be classified according to other criteria (penstock, technological concept, linkage with a network, etc.).

Table 1
Small hydropower plants in Serbia.

N	Name	River	Municipality	Owner	Power (MW)
1	Radaljska banja	Radalj	Mali Zvornik	EPS[a*]	0.27
2	Đorđić	Ljuboviđa	Ljubovija	Private	0.01
3	Vrelo	Perućačko vrelo	Bajina Bašta	EPS	0.06
4	Vrutci	Đetinja	Užice	Private	0.40
5	Turica	Đetinja	Užice	EPS	0.32
6	Pod gradom	Đetinja	Užice	EPS	0.36
7	Ovčar banja	Zapadna Morava	Čačak	EPS	6.00
8	Međuvršje	Zapadna Morava	Čačak	EPS	7.00
9	Kratovska reka	Kratovska reka	Priboj	EPS	1.50
10	Seljašnica	Seljašnica	Prijepolje	EPS	1.26
11	Moravica	Golijska Moravica	Ivanjica	EPS	0.16
12	Studenica	Studenica	Kraljevo	SOC[b**]	0.09
13	Radošićska reka	Radošićska reka	Raška	Private	0.04
14	Raška	Raška	Novi Pazar	EPS	0.80
15	Kuršumlija	Toplica	Kuršumlija	Private	0.35
16	Grčki mlin	Toplica	Prokuplje	Private	0.08
17	Sokolovica	Veliki Timok	Zaječar	EPS	5.20
18	Gamzigrad	Crni Timok	Zaječar	EPS	0.22
19	Jevtić	Crni Timok	Zaječar	Private	0.10
20	Bovan	Sokobanjska Moravica	Aleksinac	Private	0.25
21	Elektro Slavica	Trgoviški Timok	Knjaževac	Private	0.05
22	Sićevo	Nišava	Niš	EPS	1.35
23	Sveta petka	Nišava	Niš	EPS	0.60
24	Temac	Temštica	Pirot	EPS	0.78
25	Tegošnica	Vlasina	Crna Trava	Private	0.64
26	Poštica	Poštica	Vlasotince	Private	0.70
27	Livađe	Darkovačka reka	Crna trava	Private	0.45
28	Vučje	Vučjanka	Leskovac	EPS	0.93
29	Munja	Vrla	Vladičin Han	Private	0.03
30	Jelašnica	Jelašnica	Vladičin Han	EPS	0.40
31	Prvonek	Banjska	Vranje	EPS	0.91

[a*] EPS—Electric Power Industry of Serbia.
[b**] SOC—Serbian Orthodox Church.

So far, 69 SHPs have been built on the rivers in Serbia, but the majority of them is in poor condition. Out of that number, 31 with a total power of 31.3 MW and an annual electricity production of 150 GWh are in use. Thirty-eight facilities with a total power of 8.7 MW are out of use [20]. The Electric Power Industry of Serbia (EPS) is in charge of 18 SHPs and they are included in the national electrical energy system, whereas the remaining 13, which are independent, have the status of privileged electricity producers (Table 1 and Fig. 1).

This sort of incentive is provided for by the Energy Law of the Republic of Serbia and it implies a privileged position in the market compared to other energy producers who sell energy under equal conditions; it also implies a right to subsidies (tax, tariff and other subsidies provided for by law), as well as the incentive feed-in tariffs (for small hydropower plants in the Republic of Serbia) (Table 2).

3.3. Institutional, legal and planning framework in Serbia

The laws passed in recent years in Russia [2], Brazil [10] and especially Turkey [3] succeeded in promoting the utilization of renewable energy for electricity generation. Their enforcement was followed by a boost in SHP programmes and hydropower development.

The increasing topicality of renewable energy sources in Serbia has emphasized the need for establishing a suitable legal, institutional and planning framework that would act as a positive environment for their identification and effective and sustainable

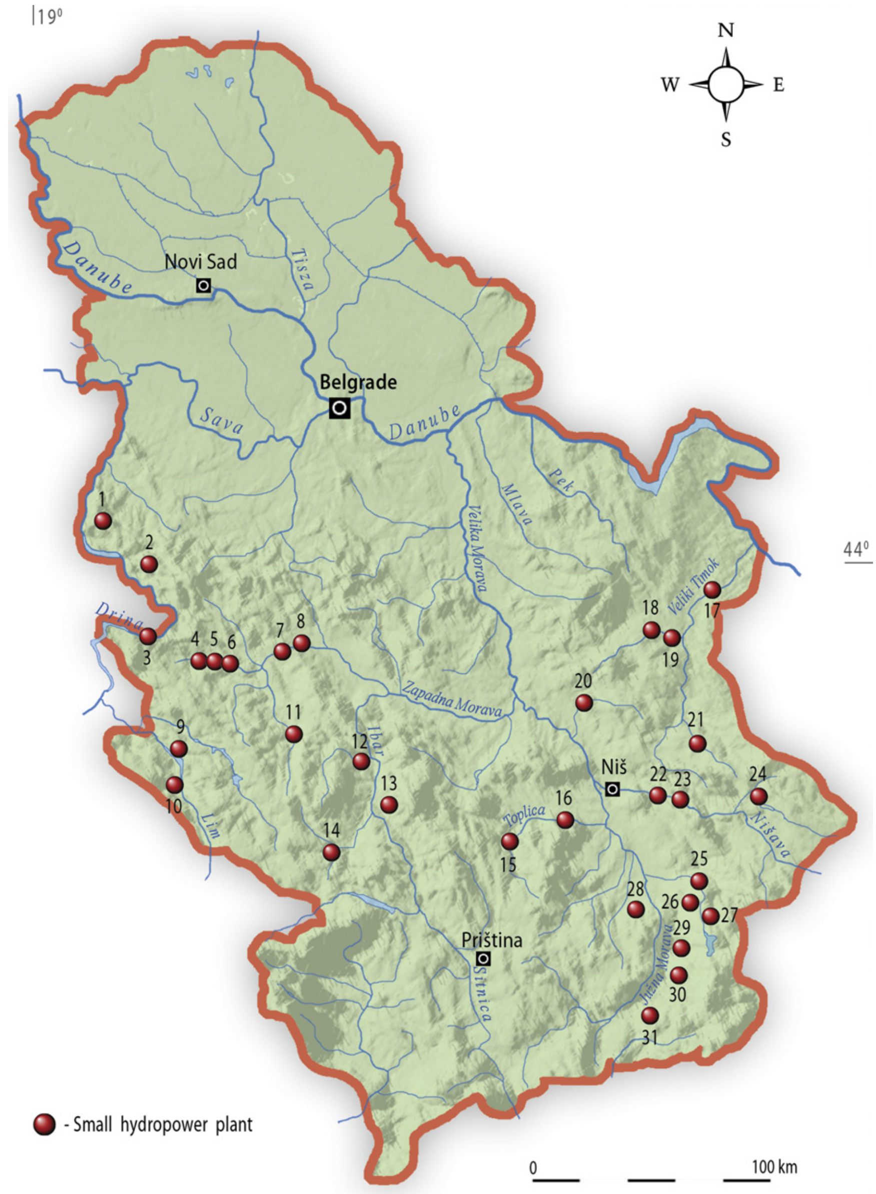


Fig. 1. Geographical distribution of small hydropower plants in Serbia, see also Table 1.

Table 2
Privileged purchase price of electricity from SHPs (c€/kWh) [19].

Categories of SHPs	Installed power P (MW)	Incentive purchase price (c€/kWh)
Newly built facilities	< 0.2	12.40
Newly built facilities	0.2–0.5	13.727–6.633×P
Newly built facilities	0.5–1	10.41
Newly built facilities	1–10	10.74–0.337×P
Newly built facilities	10–30	7.38
At the existing infrastructure	< 30	5.90

utilization. The basis to start these processes were provided by the *ratification of the Treaty establishing the Energy Community*, by which the Republic of Serbia agreed to adopt and carry out the plan for the implementation of the Directive 2001/77/EC on the promotion of electricity produced from renewable energy sources, to enforce a set of regulations on climate change aimed at reducing greenhouse gas emissions and to accede the International Renewable Energy Agency (IRENA) [21,22].

Since the issues related to obtaining electrical energy from SHPs require detailed legislation concerning the location of such facilities, their construction and their future sustainable utilization and functioning, it was necessary to draft a set of complementary laws and legal acts. The established legal framework is subjected to permanent improvement and harmonization with the legislation of the European Union. The main document in this framework is the Energy Law of the Republic of Serbia (Official Gazette of the Republic of Serbia 84/04, 57/2011), which in general terms regulates renewable energy sources, including SHPs in their most basic and general sense and lists other legal acts that have to be adopted. The legal documents that in detail regulate particular issues related to SHPs include: the Law on Planning and Construction (Official Gazette of the Republic of Serbia 72/09, 81/2009), Law on Environmental Protection (Official Gazette of the Republic of Serbia 135/04, 36/2009), Law on Waters (Official Gazette of the Republic of Serbia 30/2010), Law on Concessions (Official Gazette of the Republic of Serbia 55/2003), Law on Public Enterprises and

Performing Activities of General Interest (Official Gazette of the Republic of Serbia 25/2000, 25/2002, 107/2005, 108/2005) and other legal acts.

It should be pointed out that legal acts which specifically regulate the functioning of SHPs and provide the necessary stimulation and guidelines for investors in the mentioned area (Decree on the requirements for obtaining the status of the privileged electric power producer and the criteria for assessing fulfilment of these requirements, model agreement on purchasing electric power from privileged producers) were adopted in 2009 and the decree on incentive measures for privileged electric power producers was adopted in January 2013.

In order to ensure the implementation of the adopted legal acts, an institutional framework was established; it consists of responsible institutions: the Ministry of Energy, Development and Environmental Protection, Ministry of Natural Resources, Mining and Spatial Planning, Ministry of Agriculture, Forestry and Water Management, Provincial Secretariat for Energy and Mineral Resources of the Autonomous Province of Vojvodina, local self-government units, Energy Agency, regional centers for energy efficiency and other responsible institutions in this area.

The energy development strategy of the Republic of Serbia until 2015 was devised with the aim of identifying renewable energy sources in Serbia and the types of and possibilities for their utilization in future. This document points out the hydropower potential of large rivers like the Morava, Drina, Lim and Danube, on which the construction of individual facilities of a power greater than 10 MW is foreseen, and small rivers on which SHPs would be installed, as the most important renewable energy source in Serbia. In order to ensure that the aims set by this document are put into practice, the Programme for the Implementation of the Energy Development Strategy from 2007 to 2012 (Official Gazette of the Republic of Serbia 170/2007, 73/2007) was devised.

The Spatial Plan of the Republic of Serbia from 2010 to 2020 (Official Gazette of the Republic of Serbia 88/10) deals with the locations for possible construction of SHPs in the territories of Serbia and it suggests consulting the above-mentioned Surveys in order to get a general idea of what locations are favorable for such facilities. At the same time, a great number of these locations have been assessed as unacceptable and it was necessary to provide for the obligation to carry out additional exploration. The Spatial Plan of the Republic of Serbia singles out a group of the most prospective locations for the construction of SHPs which will be granted special attention in near future and whose exploitation potential will be fully analyzed.

3.4. Administrative procedure for SHPs development

Administrative procedure for acquiring the right to design, construct and operate SHPs in Serbia involves three main steps. The first step is the selection of the location, which means finding a location that is according to the Survey [18] allocated for the construction of SHPs. Potential investor should then visit the location and check whether it is included in the planning documents. In some cases, it is possible to construct SHPs on other locations (not allocated for the construction of SHPs according to the Survey) as well, but it is necessary to obtain the approval by relevant ministries and institutions.

The second step is related to acquiring the right to construct a SHP, which means that the potential investor should obtain five licenses: an energy license (only for 1 MW facilities or larger), a location permit, a construction permit, a water permit and an operating permit. The issuing of the location, construction and operating permits is within the jurisdiction of local government units. If the SHP is in the vicinity of a national park or within a protected area, permits are in jurisdiction of the Ministry of Energy, Development and Environmental Protection (with the assessment of the Institute of Nature Conservation of Serbia) or relevant authorities of the Autonomous Province. Environmental Impact Assessment may be required for SHPs exceeding 2 MW, and in that case, decision is made by a local government unit based on relevant environmental authority opinion and general public opinion.

The third step is related to acquiring the right to engage in power generation. A potential investor needs the assignment agreement approved by the the Ministry of Energy, Development and Environmental Protection, a license to engage in an energy-related activity (only for 1 MW facilities or larger) approved by the Energy Agency, the approval to connect to the electric power grid, the status of a privileged electric power producer and a power purchase agreement with the Electric Power Industry of Serbia.

During the procedure, apart from these basic documents, it is necessary to obtain a number of supporting documents and approvals required by laws and regulations. Along with the mentioned authorities and institutions, this complex process also involves other ministries and agencies.

3.5. Possibilities for future SHP development in Serbia

Conducted research shows that the greatest hydropower potential usable for SHPs is located in the west (in the Kraljevo and Užice regions) and south (the Niš region) parts of Serbia, which are mountainous areas (Table 3). The greatest number of such facilities could be installed in the region where the first small hydropower plant in Serbia was built—in the Užice region. In the northern, flatland area of Serbia (Podunavlje, Vojvodina, the Belgrade area), hydropower potential is somewhat lower but,

Table 3
Potential number of small hydropower plants that could be built in Serbia by administrative regions.
Source: prepared from data in Ref. [18].

Region	Installed power (MW)	Annual electricity production (GWh)	Number of SHPs
Kraljevački	96.1	308.5	158
Užički	93.2	357.7	203
Južno-moravski	77.2	295.9	177
Niški	75.7	284.2	141
Zaječarski	48.5	52.1	70
Podrinjsko-Kolubarski	23.7	76.0	62
Šumadijsko-Pomoravski	15.4	36.9	16
Podunavski	12.5	33.4	27
Vojvodina (uz DTD)	10.4	54.0	13
Beogradski	0.32	0.307	2
TOTAL	453	1 499	869

Table 4
Municipalities in Serbia with the greatest hydropower potential for SHPs [23].

Municipality	Installed power (MW)	Annual electricity production (GWh)	Number of SHPs
Ivanjica	34.3	121.2	64
Raška	33.3	109.7	35
Pirot	25.9	94.0	40
Kraljevo	23.5	78.4	40
Prijepolje	18.8	74.0	47
Zaječar	17.6	60.2	9
Crna Trava	17.0	72.2	22
Novi Pazar	15.8	55.1	20
Bela Palanka	15.7	58.9	8

having in mind that these regions are the most densely populated and economically most developed parts of Serbia, it should also be taken into account.

In order to meet the needs of local communities interested in the construction of SHPs, reports on the hydropower potential for municipality in Serbia were drafted in 2006 (Table 4). It shows that the municipalities with the great potential for the construction of SHP are located in the southwestern, western and southern areas of Serbia.

Environmental issues are important factors that have to be considered in the planning, construction and utilization of SHPs; in Serbia, these issues are addressed by relevant laws and regulations, which are to a varying degree harmonized to European laws and standards. European environmental legislation (Natura 2000, Directives on the Environmental Impact Assessment and the Strategic Environmental Assessment, the Water Framework Directive, etc.) and national implementing laws hinder the development, the operation and the refurbishment of SHP plants. Thus the current situation of small hydropower development in many of the EU-27 Member States can be rather described as survival than development. In several Member States measures have been taken which have a very negative impact on small hydropower, like Poland ("Moratorium for SHPs"), in Slovenia (new decree on residual flow), in France (new river classification), etc. [24]. Having in mind the negative experiences of those countries it may be expected that the adoption and implementation of the mentioned directives in the national legislation would be accompanied by the decreased total hydropower potential for SHPs in Serbia.

3.6. Significant problems for SHP development in Serbia

Although the benefits of the utilization of SHPs have been identified and recognized as a positive solution and approach to electric power production in Serbia, attempts to implement this approach in practice are inevitably accompanied by numerous problems which significantly delay and hinder, and sometimes even entirely obstruct the process.

One of the major problems is the administrative 'vicious circle' that accompanies permit-issuing procedures; investors interested in SHP projects often get lost in it, having to cope with numerous difficulties and exceptional circumstances. When choosing the location for a SHP based on data provided by Survey [18], it happens that the selected location is not available any more either because it was re-purposed or it is protected by law and cannot be used for construction. To begin construction of the facility, the investor must collect 27 different permits, approvals and other documents.

Although the broader institutional, legal and planning framework related to the utilization of renewable energy sources and SHPs have been established (see Section 3.3), the process of issuing necessary permits and approvals is not sufficiently transparent, it involves a large number of institutions which do not interact with each other and consumes considerable time (at average, 2 years) and financial means without a guarantee that the planned project will eventually be implemented.

Financial issues are another major problem accompanying the implementation of SHP-related projects. As for small-scale investments, investors usually decide to cover a part of expenses by bank loans. However, as the practice has shown, banks offer varying repayment conditions, which are particularly reflected in varying annual repayment interest. As far as large-scale investments are concerned, investors apply for loans at EBRD. In December 2011, EBRD approved a loan of 45 million euros to the Electric Power Industry of Serbia for the reconstruction of 15 small hydropower plants with a total capacity of 18 MW and the construction of seven new SHPs on the existing dams with a total capacity of 13 MW [25]. However, it turned out that funds were not timely spent. Since the project involved a large number of locations, it was necessary to provide extensive project documentation. Accordingly, the Electric Power Industry of Serbia is compelled to pay expenses related to unallocated and unused funds. This further confirms the above-mentioned statement that the procedures for issuing permits and approvals for SHP projects are complicated.

4. Case study: SHP Tartići

The SHP Tartići is located on the Sokolska River and the Zakućanski Potok stream, in the Ljubovija municipality, in the western part of Serbia. Its construction is underway; it was begun in 2012 and should last in 18 months. The SHP is designed as a derivation facility, highly automated, with supply water pipes, pressure piping systems and Kaplan turbine (Fig. 2). With net head of 40.5 m and the installed discharge of 0.55 m^3/s, the installed capacity of the hydropower plant is 185 kW and the expected

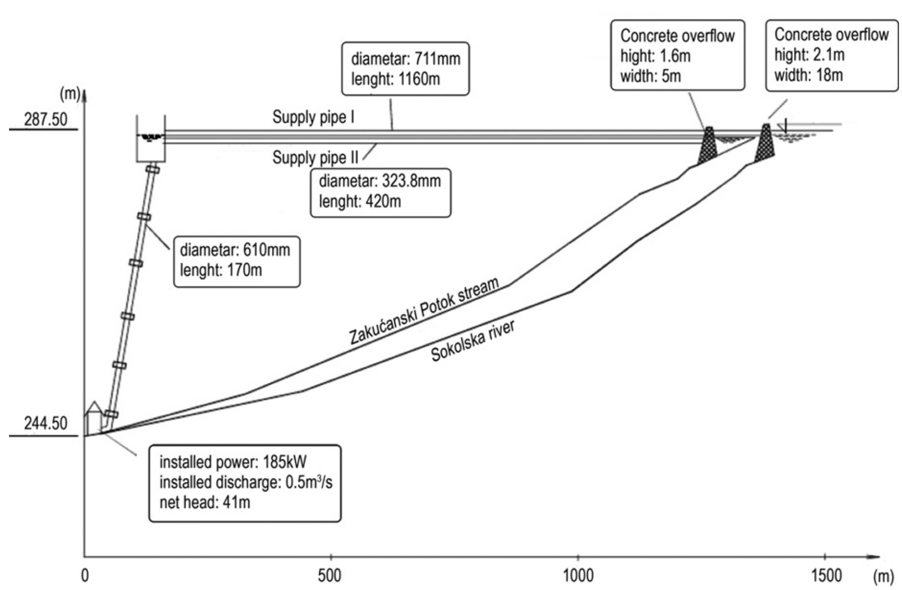


Fig. 2. Hydraulic scheme of the SHP Tartići.

average annual energy production is 0.75 GWh. The entire amount of the energy produced by this plant will be transferred to the network of the Electric Power Industry of Serbia.

The total investment for this small hydropower plant is 459,750€, 80% of which is funded by a ten-year bank loan with an interest rate of 5.70% per year and a 2-year grace period; the remaining 20% are investors' equity. The economic life of the SHP is 30 years and the financial plan and profitability are summarized in Table 5 [26].

Initial costs of the facility, presented in Table 6, show the distribution and share of various group of costs. The average unit cost of the facility is 2485 €/kW.

Other costs related to SHP operation include employees' salaries and remunerations; calculated for three necessary employees, they reach the amount of 6150€ per year; the machinery break down insurance and fire insurance amount to 1380€ per year; the amortization costs, which are directly related to the technological life of the facility and equipment, amount to 10,020€.

The average unit cost of the electric power produced at this SHP will be 4.19 c€/kWh; excluding profit and interest, it will be reduced to 3.08 c€/kWh. In accordance with the recently adopted Decree on Incentive Measures for Privileged Electric Power Producers, the electric power purchase price for this SHP is 12.4 c€/kWh.

Table 5
Financial plan and profitability of SHP (euros).

Bank loan	367,750
Equity of investors	92,000
Total investment	459,750
Gross annual income	93,715
Net annual income	55,066
Simple payback time	4 years and 9 months
Net present value	454,048
Coefficient net present value	0.99
Internal rate of return (IRR)	30.58%

Table 6
Summary of the initial costs of the facility (euros).

Designing, planning and project management	23,180
Construction costs	150,030
Mechanical equipment	151,300
Electrical equipment	81,600
Transport and setup	18,970
Contingencies	34,670
Total	459,750

5. SHPs within the existing water management infrastructure

The utilization of the hydropower potential of municipal water supply dams also has an important role. Kucukali [7] has estimated that the installation of SHPs into 45 already existing municipal water supply dams in Turkey would enable to generate 173 GWh of electric energy per year, corresponding to an economic benefit of 17,000,000 EUR/year, without affecting the natural environment.

It has been planned that by 2015 the available surplus hydropower potential at the existing water supply dams and water reservoirs in the Republic of Serbia should be utilized for energy production at newly built small hydropower plants. The investor of this project should be the Electric Power Industry of Serbia, either alone or in collaboration with a strategic partner. In collaboration with the Jaroslav Černi Institute, the Electric Power Industry of Serbia selected eight most promising projects for further analysis. These projects foresee the construction of SHPs at the reservoirs of Ćelije, Bovan, Barje, Vrutci, Zlatibor, Parmenac, Selova and Rovni (Table 7). The funds for the construction of these facilities would be partially provided by the investor, and partially from an EBRD loan.

The Ćelije dam and reservoir on the Rasina River were built in 1979 as a multi-purpose water management system. They are located 33 km upstream from the river's confluence into the Zapadna Morava River. The Bovan dam and reservoir on the Moravica River were constructed in 1979 as a multi-purpose water management system within the scope of the Velika Morava river basin management project. They are located in Bovanska Gorge between the village of Bovan and Sokobanja. The Barje dam and reservoir were constructed in 1991 as a multi-purpose water management system. They are located in the immediate vicinity of the village of Barje, Leskovac Municipality. The Vrutci dam and reservoir on the Đetinja River were built in 1983. They are located 12 km upstream from Užice. The Ribnica dam and reservoir on the Crni Rzav River were built in 1972 as a water supply system for the settlements on Zlatibor Mountain. They are located on Zlatibor Mountain, near the village of Ribnica, Čajetina Municipality. The Pramenac dam and reservoir were constructed in 1957 to supply water to the irrigation system, but the reservoir was also used as a compensation basin for the Međuvršje Hydropower Plant, whereas nowadays its supplies water to the town of Čačak (as an alternative water source). They are located about 5 km upstream from Čačak. The Selova dam and reservoir on the Toplica River are still under construction. They have been intended as a segment of the regional water management system supplying water to Niš, Merošina, Kuršumlija, Prokuplje, Blace and Žitorađa. They are located 18 km upstream from Kuršumlija. The Rovni dam and reservoir on the Jablanica River are still under construction and they are intended to supply water to Valjevo, Lazarevac, Lajkovac, Ub and Mionica. They are at about 15-km distance from Valjevo.

Table 7
Small hydropower plants at the existing water management infrastructure.
Source: prepared from data in Ref. [27].

SHPs	Mean discharge (m^3/s)	Installed discharge (m^3/s)	Head (m)	Installed power (MW)	Average annual production (GWh)	Investment (million €)
Ćelije	5.84	9.0	42.8	3.4	11.6	3.2
Bovan	3.27	5.5	32.9	1.6	5.2	2.5
Barje	2.33	4.5	50.9	2.0	5.1	2.6
Vrutci	2.04	3.6	50.3	1.6	4.8	3.1
Zlatibor	1.01	1.2	19.7	0.2	0.8	0.5
Parmenac	33.7	50.0	4.1	1.8	7.8	5.1
Selova	3.47	5.5	57.7	2.8	13.3	3.1
Rovni	1.34	2.1	70.1	1.3	5.2	1.6

Apart from the SHPs in Central Serbia presented in Table 7, the Danube–Tisza–Danube hydro-system in the AP Vojvodina, has the potential for construction of SHPs at the existing weirs and locks. The construction of 12 SHPs with the total installed power of 20.2 MW and an expected average annual energy production of 90.7 GWh has been planned. The construction of such facilities would significantly increase the flow capacity of the canal network, which is expected to have an environmentally beneficial effect [17].

5.1. *Case study: SHP Prvonek*

The SHP Prvonek is located at the foot of the Prvonek dam. The Prvonek reservoir, with a total capacity of 23,000,000 m^3, serves as drinking water supply for the municipalities of Vranjska Banja, Vranje, Bujanovac and Preševo. The SHP Prvonek is the first electric power facility built in compliance with the Decree on the Implementation Programme of the 2015 Energy Development Strategy, namely, with its provisions related to the construction of new electric power plants within the existing water management facilities. The SHP Prvonek may be regarded as a model for the implementation of similar projects in future, i.e. for the construction of SHPs within other water management facilities. Furthermore, the SHP Prvonek is the first electric power facility built by the Electric Power Industry of Serbia in the past 20 years and the first facility to produce energy to be sold at the feed-in tariff in accordance with the Decree on Incentive Measures for Privileged Electric Power Producers. The project documentation for the construction of this facility was drafted during 2010. Calls for tenders and equipment procurement were carried out late in 2010 and early in 2011. The construction was completed between June and December 2011. The facility was inaugurated on April 25, 2012.

The SHP has two hydro-aggregates: a small one, which employs reserved flow for electric power production, and the larger one, which uses available surplus water from the reservoir for energy production. Water is supplied to the small hydro-aggregate via a short steel pipeline with a diameter of 300 mm. The large hydro-aggregate is supplied with water through a 145 m long steel pipeline with a diameter of 800 mm. The plant is connected to a 10-kV electricity distribution network through a 10/0.4 kV transformer station placed in the machinery hall.

The operation control system of this small hydropower plant is integrated with the operation control system of the reservoir; accordingly, the owner (user) of the dam controls the water release regime, including the water release through the hydro-aggregates within the SHP. Both aggregates are equipped with horizontal-axis Francis turbines. The large hydro-aggregate has the net head of 76 m and the installed discharge of 1.2 m^3/s, whereas the small hydro-aggregate has the net head of 50 m and the installed discharge of 0.25 m^3/s. Synchronous generator parameters are the same for both hydro-aggregates: the voltage of 0.4 kV and the frequency of 50 Hz. The total installed power is 0.91 MW, whereas the expected annual production is 3 GWh. The funds for the construction of the SHP, which amounted at about 1.6 million euros, were entirely provided by the Electric Power Industry of Serbia [27].

6. Conclusion

Although the idea of installing SHPs in Serbia emerged already in the early 20th century, which was followed by the construction of several dozen such facilities, more recent political and economical changes caused a significant delay in their development compared to other countries. In Serbia, only 31 SHPs producing about 150 GWh of electric energy per year are in use, which is in disproportion to the current trends in the EU-27 countries (there are more than 400 SHPs in Slovenia; 6200 in Germany; 1730 in France; 1700 in Austria; 1615 in Sweden; 1510 in Italy and 1106 in Spain).

Although relevant legislation and planning documents seek to promote a more intensive exploitation of the mentioned energy source due to its numerous advantages (environmental protection, reduction of fossil fuel use, utilization of the hydropower of small watercourses, increased national electricity generation, i.e. reduced need for imported electricity, long life of hydropower plants—about 50 years on the average, increased automation, a more rapid electrification of inhabited places and facilities distant from the electricity grid), there are numerous limiting factors which hinder and impede it. The greatest disadvantages of SHPs are related with great costs accompanying the exploration of potential sites for their construction (costs of preliminary and main project drafting), complicated permit-issuing procedures and the great initial investments. The application of methods based on GIS, which allows to survey precisely large areas in a short period of time, could reduce the cost of location analyses. This approach could be used in devising the policy for the SHP development and ensuring an improved convenience for the user. Taking into account global climate changes, significant reductions in hydropower yields need to be considered in future water management plans in Serbia. New proposals for the construction of small hydropower plants may have to be re-assessed in terms of economic cost-effectiveness and environmental sustainability, taking into account the outlined conditions dictated by possible future scenarios. Apart from the mentioned issues, other problems include low awareness of the advantages of SHPs both among professionals and the public, insufficient knowledge of technologies, economic and ecological indicators, as well as the payback time estimation, an underdeveloped market and limited funds for investing in projects in this area.

Having in mind the mentioned advantages and limits for the construction of SHPs, some of the possible solutions would include drafting of the new Survey of SHPs in Serbia; a long-term Energy Strategy; strict application of ecological measures when planning and devising projects for SHPs in compliance with EU directives; defining criteria and rules for the utilization of watercourses for SHPs and strict control of development activities and resource exploitation.

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References

[1] Alonso-Tristán C, González-Pena D, Díez-Mediavilla M, Rodríguez-Amigo M, García-Calderón T. Small hydropower plants in Spain: a case study. Renewable and Sustainable Energy Reviews 2011;15(6):2729–35.
[2] Blyashko I. Modern trends in the development of small hydro power around the world and in Russia. Thermal Engineering 2010;57(11):953–60.
[3] Kucukali S, Baris K. Assessment of small hydropower (SHP) development in Turkey: laws, regulations and EU policy perspective. Energy Policy 2009;37(10):3872–9.
[4] Zhou S, Zhang X, Liu J. The trend of small hydropower development in China. Renewable Energy 2009;34(4):1078–83.
[5] Dursun B, Gokcol C. The role of hydroelectric power and contribution of small hydropower plants for sustainable development in Turkey. Renewable Energy 2011;36(4):1227–35.

[6] Balat H. A renewable perspective for sustainable energy development in Turkey: the case of small hydropower plants. Renewable and Sustainable Energy Reviews 2007;11(9):2152–65.
[7] Kucukali S. Municipal water supply dams as a source of small hydropower in Turkey. Renewable Energy 2010;35(9):2001–7.
[8] Aslana Y, Arslan O, Yasara C. A sensitivity analysis for the design of small scale hydropower plant: Kayabogazi case study. Renewable Energy 2008;33(4): 791–801.
[9] Nautiyal H, Singal SK, Varun, Sharma A. Small hydropower for sustainable energy development in India. Renewable and Sustainable Energy Reviews 2011;15(4):2021–7.
[10] Filho GLT, Galhardo CR, Barbosa AC, Barros RM, Silva FGB. Analysis of Brazilian SHP policy and its regulation scenario. Energy Policy 2011;39(10):6689–97.
[11] Ohunakin OS, Ojolo SJ, Oluseyi OO. Small hydropower (SHP) development in Nigeria: an assessment. Renewable and Sustainable Energy Reviews 2011;15 (4):2006–13.
[12] Ministry of Mining and Energy of Republic of Serbia. Energy Development Strategy of the Republic of Serbia by 2015. Official GazetteRS 44/2005.
[13] Milanović A, Milijašević D, Brankov J. Assessment of polluting effects and surface water quality using water pollution index: a case study of hydro-system Danube–Tisa–Danube, Serbia. Carpathian Journal of Earth and Environmental Sciences 2011;6(2):269–77.
[14] Lehner B, Czischb G, Vassoloa S. The impact of global change on the hydropower potential of Europe: a model-based analysis. Energy Policy 2005;33 (7):839–55.
[15] Working Group. Consideration of hydropower potential of Pirot municipality. Hydropower potential - small hydropower plants (SHPs) to 10 MW. Pirot; 2006 [in Serbian]. Available from: 〈http://www.pirot.rs/downloads/strategije/mhe_pirot.pdf〉.
[16] Stevović S. The importance and purpose of small hydropower plants and small accumulations. Vodoprivreda 2005;37(216–218):299–304 [in Serbian].
[17] Provincial Secretariat for Energy and Mineral Resources. Implementation Programme for Energy Development Strategy of the Republic of Serbia in Vojvodina by 2012. Novi Sad: Executive Council of the Autonomous Province of Vojvodina, Provincial Secretariat for Energy and Mineral Resources; 2007. p. 71–83 [in Serbian] 〈http://www.region.vojvodina.gov.rs/images/stories/strategije/09/EnergetikaUVojvodini.pdf〉.
[18] Ministry of Mining. Energy of Republic of Serbia. Survey of SHPs in Serbia. Available from: 〈http://mhe.mre.gov.rs/〉.
[19] Ministry of Mining and Energy of Republic of Serbia. Decree on Incentive Measures for Privileged Electric Power Producers. Official Gazette RS 8/2013.
[20] Jovanović B, Parović M. State and development of small hydropower plants in Serbia. Belgrade: Jefferson Institute; 2009 [in Serbian].
[21] Tešić M, Kiss F, Zavargo Z. Renewable energy policy in the Republic of Serbia. Renewable and Sustainable Energy Reviews 2011;15(1):752–8.
[22] Golusin M, Tesic Z, Ostojic A. The analysis of the renewable energy production sector in Serbia. Renewable and Sustainable Energy Reviews 2010;14 (5):1477–83.
[23] Ministry of Mining. Energy of Republic of Serbia. Decree on Amendments and Supplement on the Program for the Realization of theEnergy Development Strategy of the Republic of Serbia by 2015. Official Gazette RS 72/09; 2007–2012.
[24] European Small Hydropower Association ESHA. Current status of Small Hydropower development in the EU-27; 2011. Available from: 〈http://www.streammap.esha.be〉.
[25] Ina Coretchi. EBRD helps increase Serbia's renewable energy production. Available from: 〈http://www.ebrd.com/pages/news/press/2011/111220a.shtml〉.
[26] Ekoenergo Inženjering. Economical analysis of SHP Tartići (personal communication).
[27] The Jaroslav Černi Institute. Development of Water Resources. Activities and Results; 2010–2011. p. 70–1, 80–1 [in Serbian].